Thermo-mechanical FEA models development, specification, and methodology

Pawel Duda / Wroclaw University of Science and Technology

PIP-II Technical Workshop

03/12/2020

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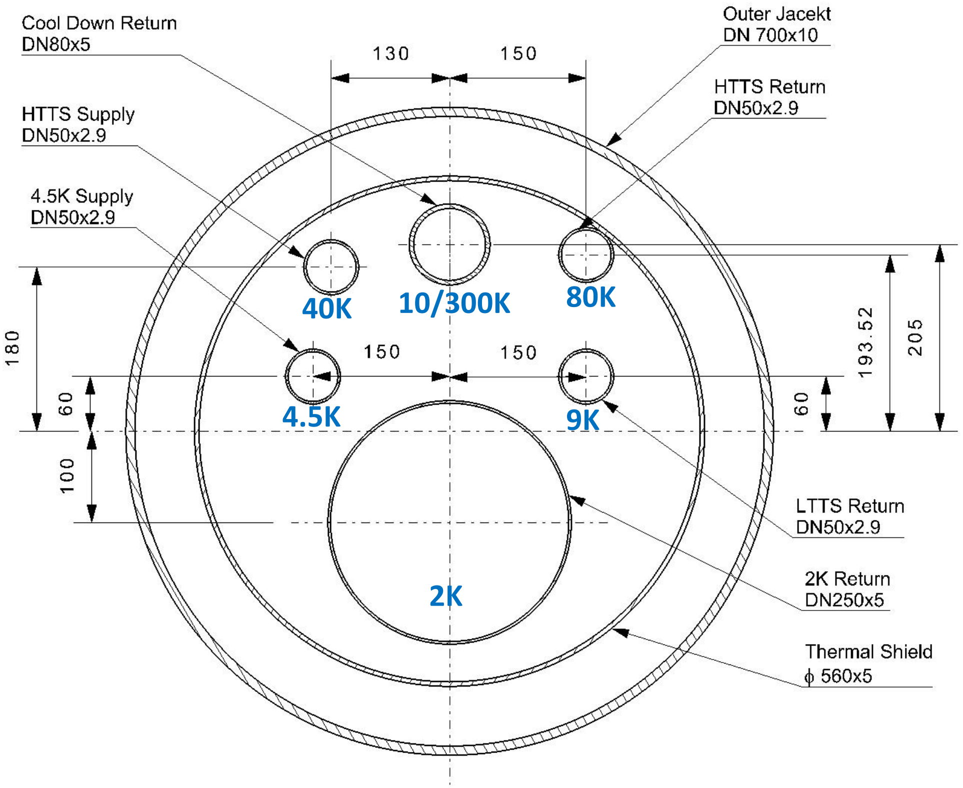
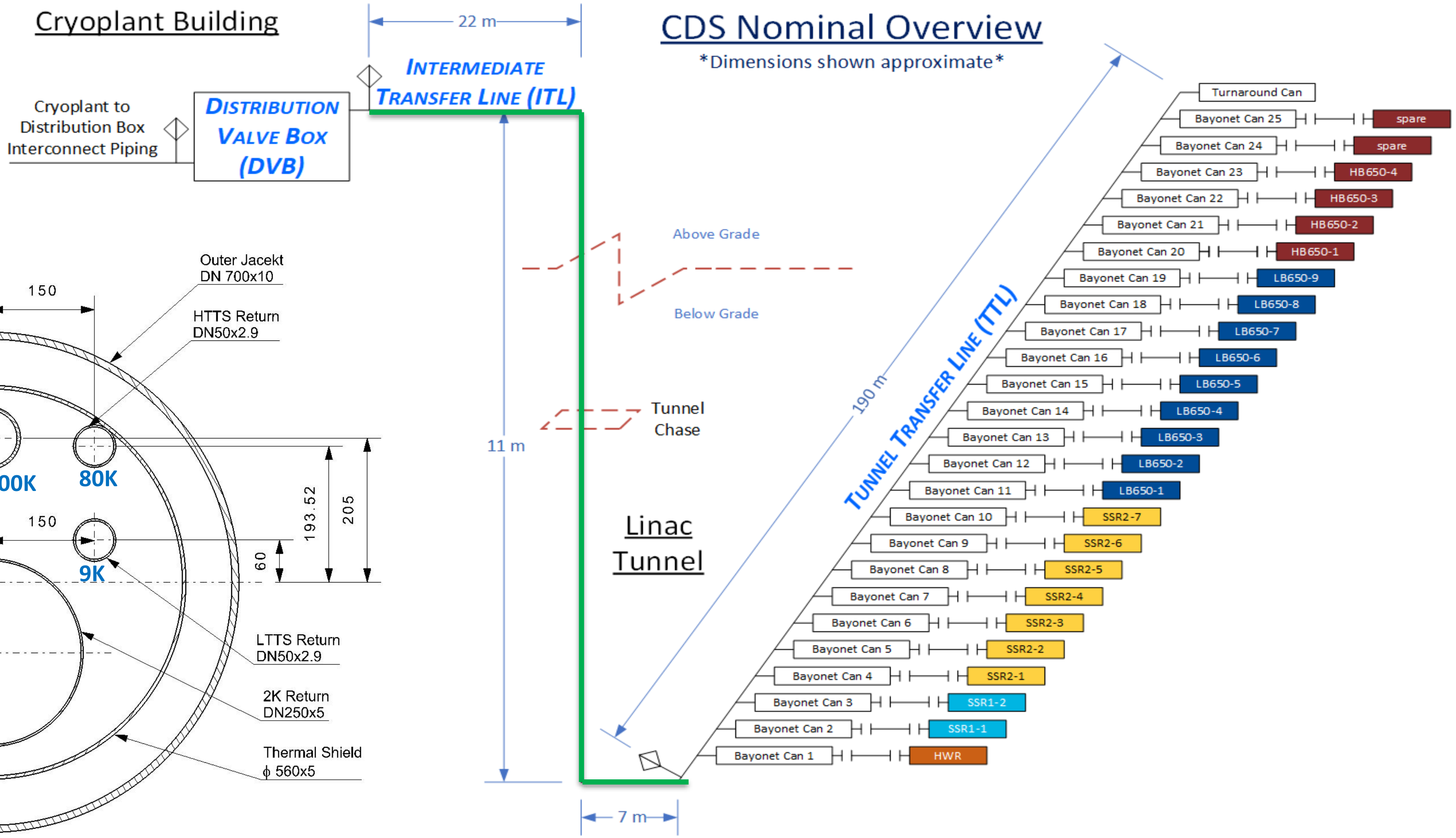
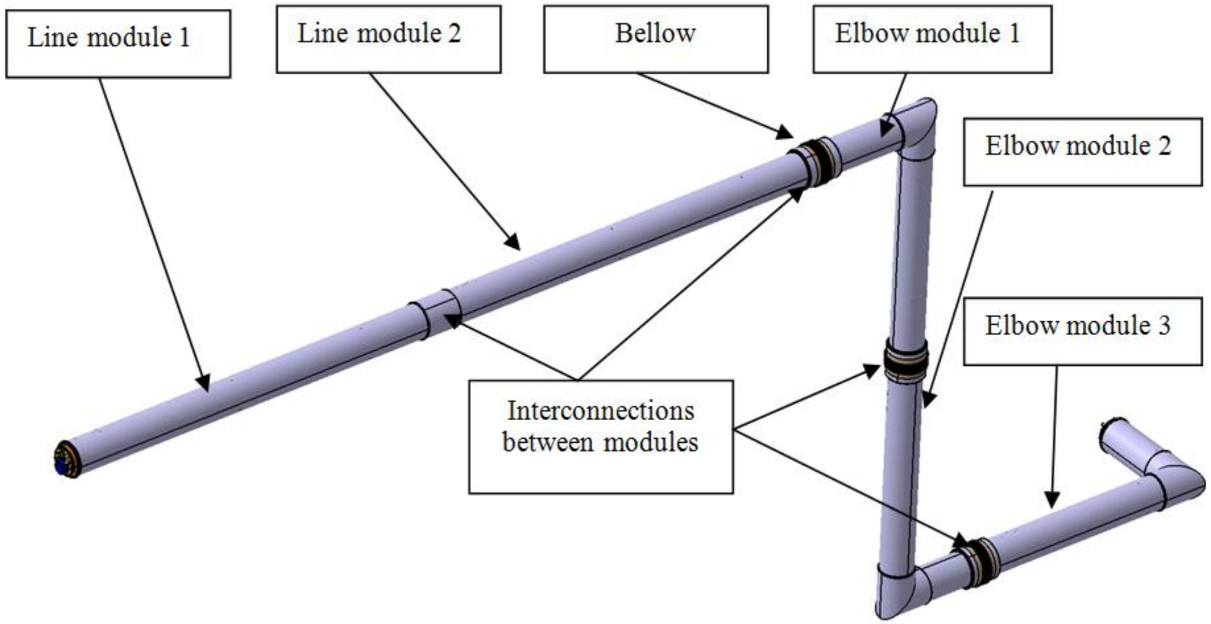
Intermediate Transfer Line model development

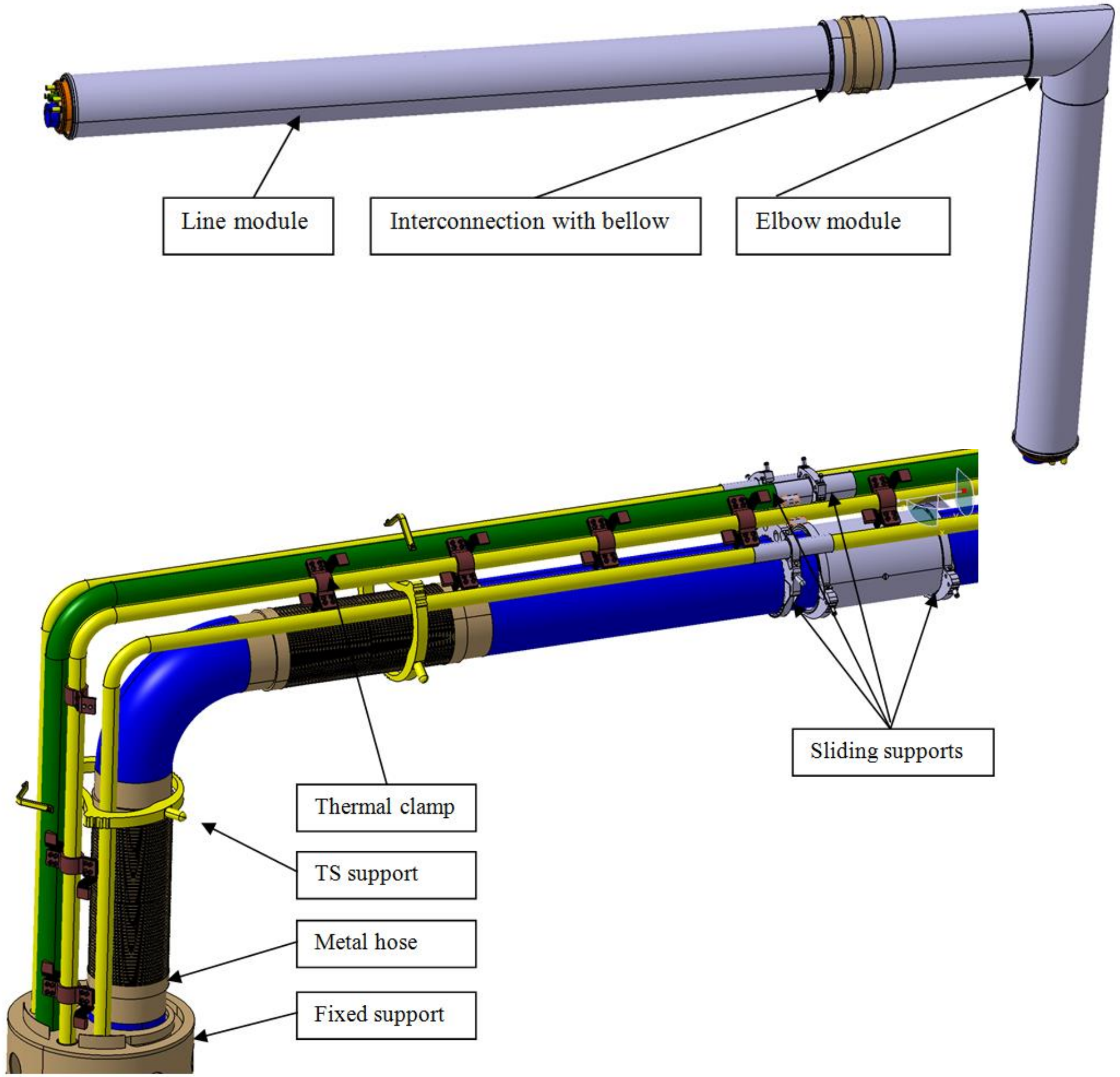
- 40 m long
- 2 horizontal and 1 vertical sections
- 3 elbows 90°



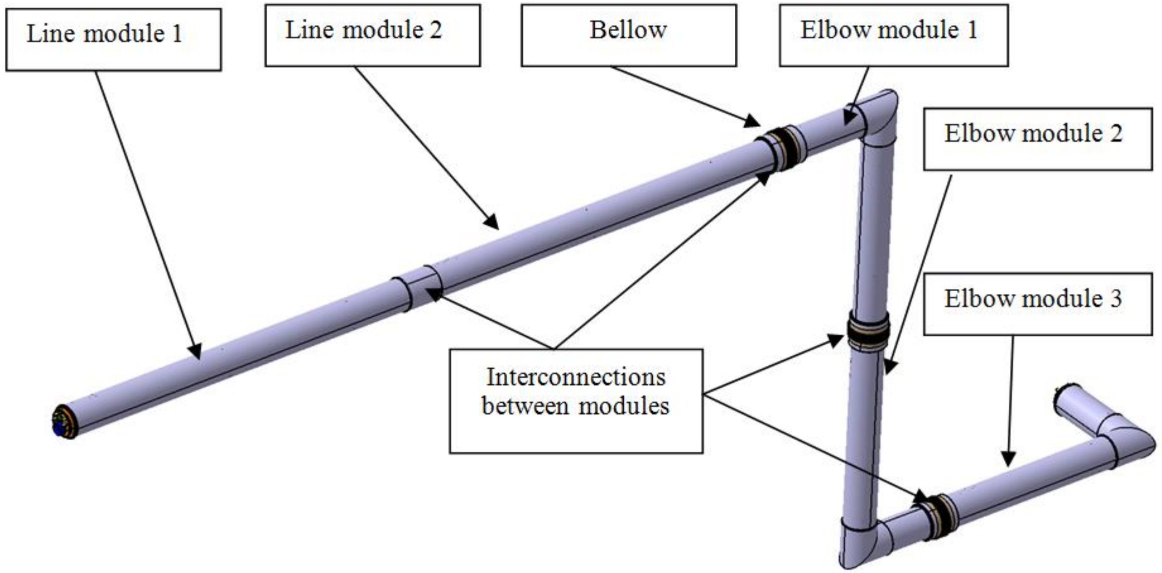


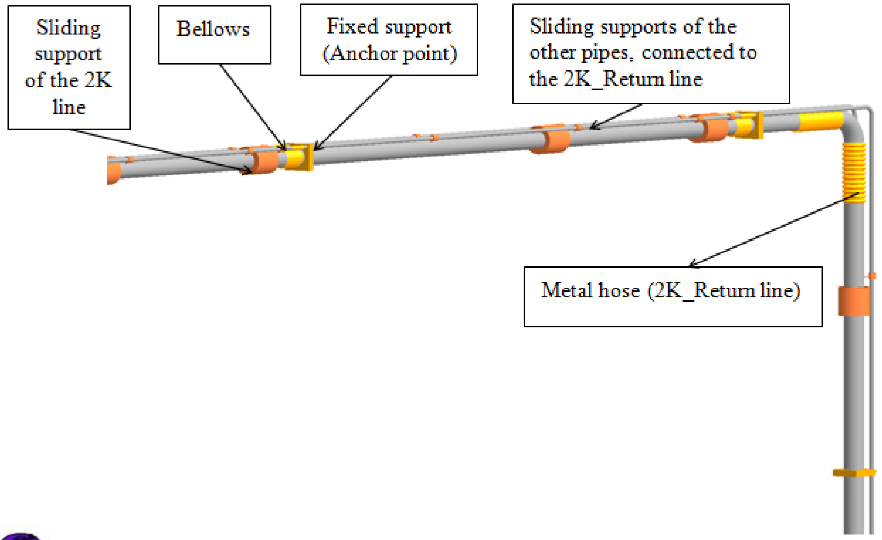
Intermediate Transfer Line model development





CaePipe model analysis - is it necessary?

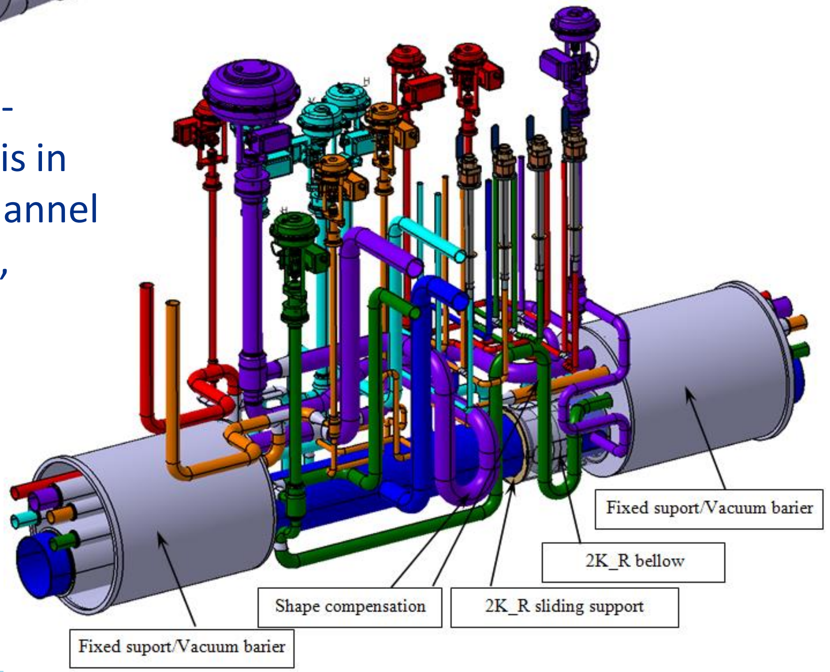


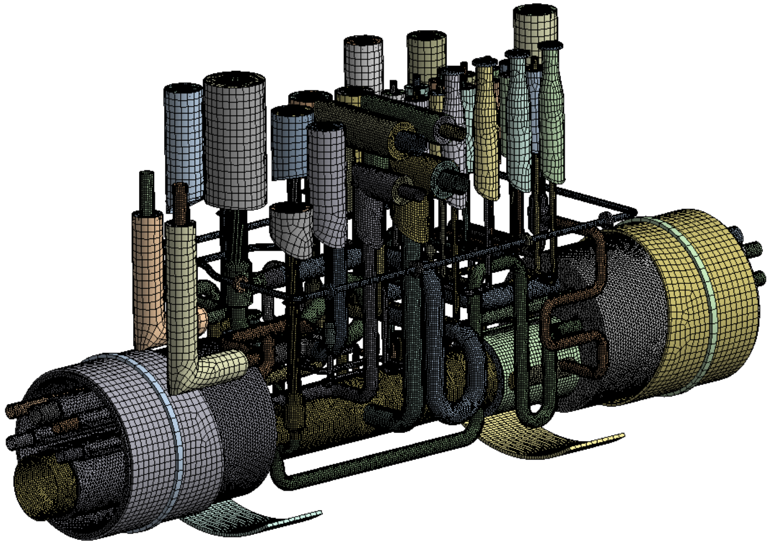


Types of models for thermo-mechanical analysis:

- long with a large number of repetitive elements - recommended thermo-mechanical initial analysis in CaePipe or similar software (multi- and single-channel transfer lines, auxiliary lines, simple valve boxes),

- devices with a complex internal structure, equipped with vessels, without repetitive elements (supports, expansion bellows, etc.) - direct analysis of the FEM 3D model is recommended

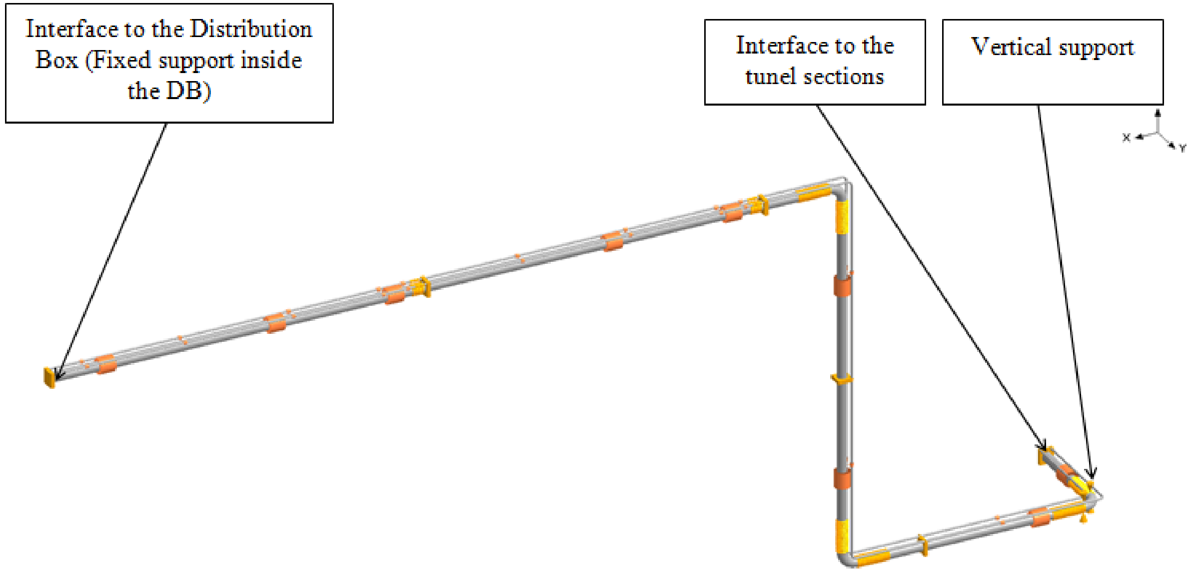


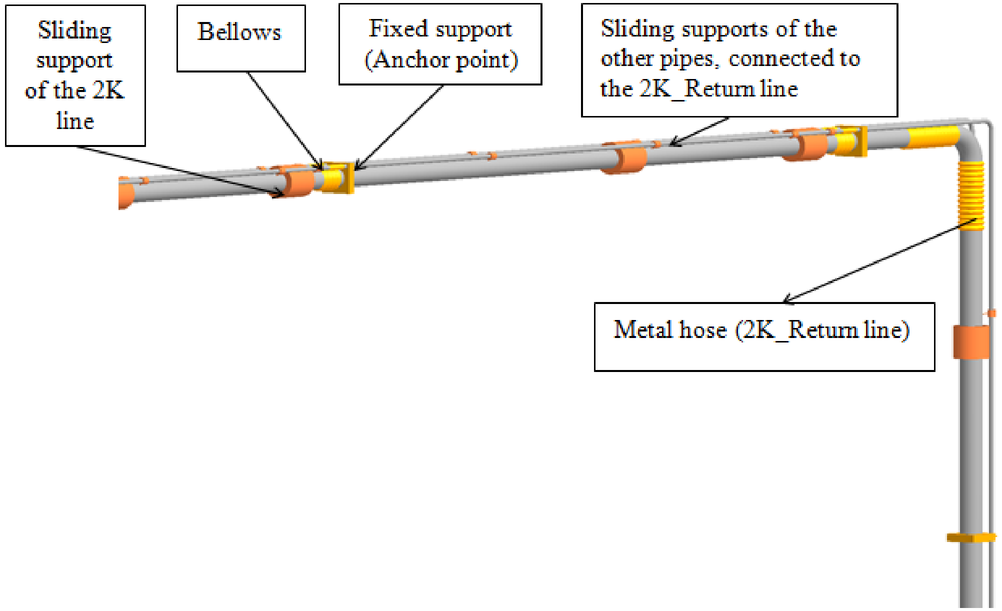


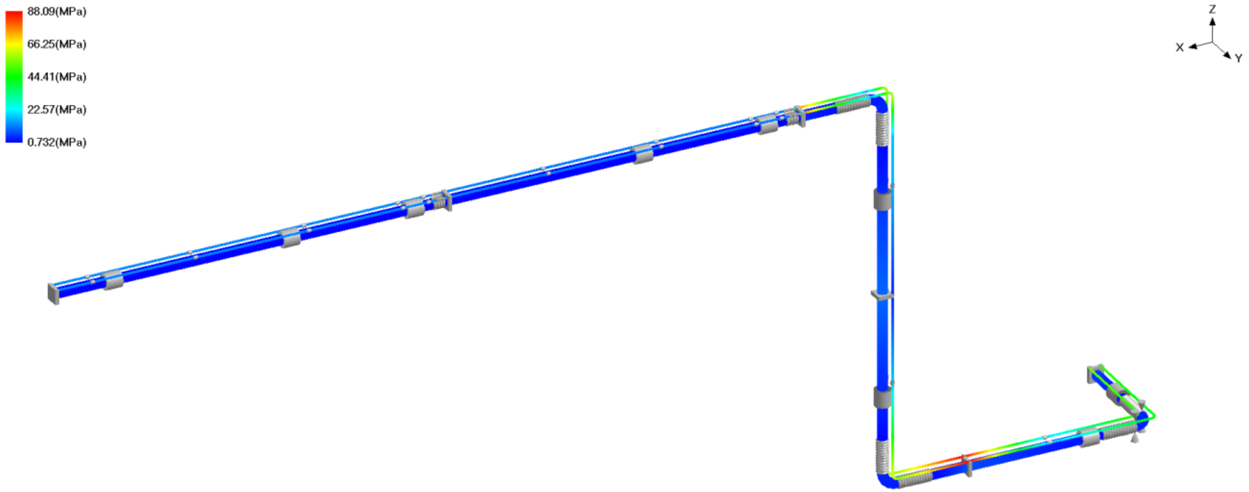
CaePipe model analysis - is it necessary?

The development of the initial model in CaePipe allows the definition of the basic geometrical and mechanical parameters of the transfer line:

- location and number of supports,
- location and number of expansion bellows
- values of forces and moments acting on supports
- places of stress concentration
- process pipe deformation values
- compensation bellows movements



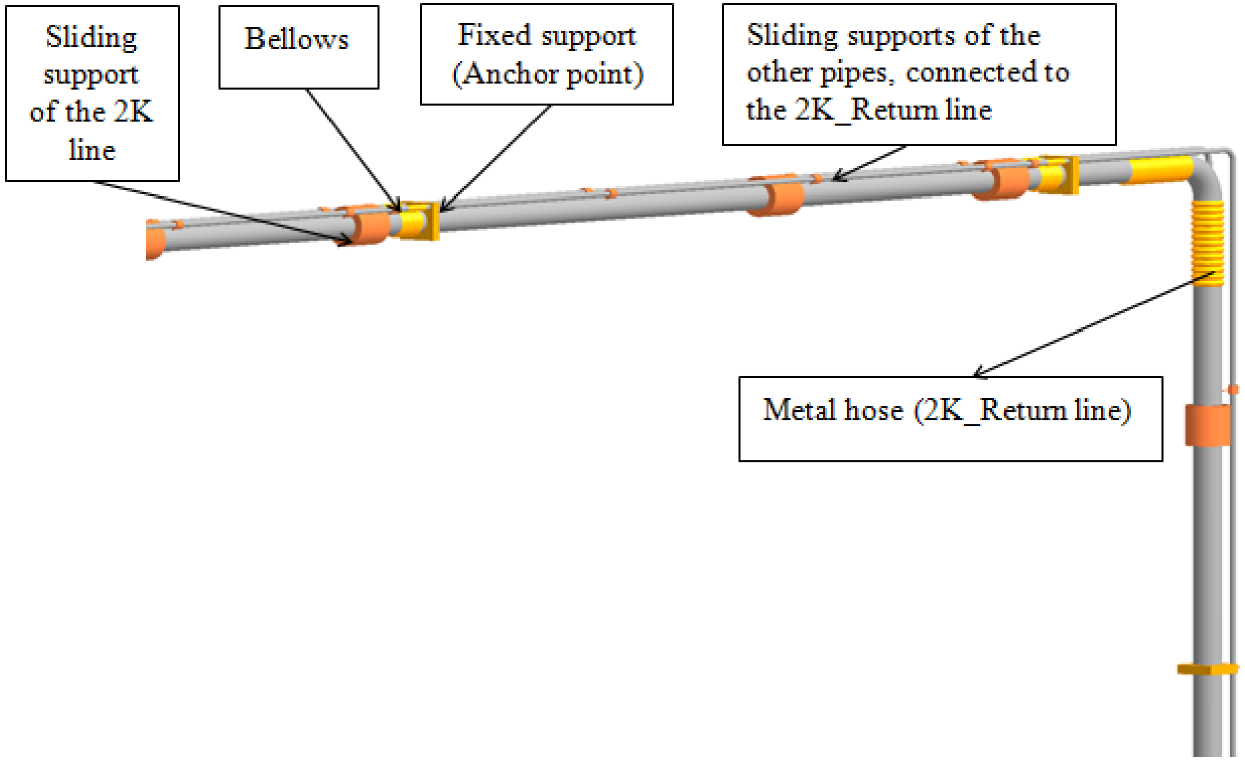




CaePipe analysis – model development and boundary conditions

Example of load cases to be considered:

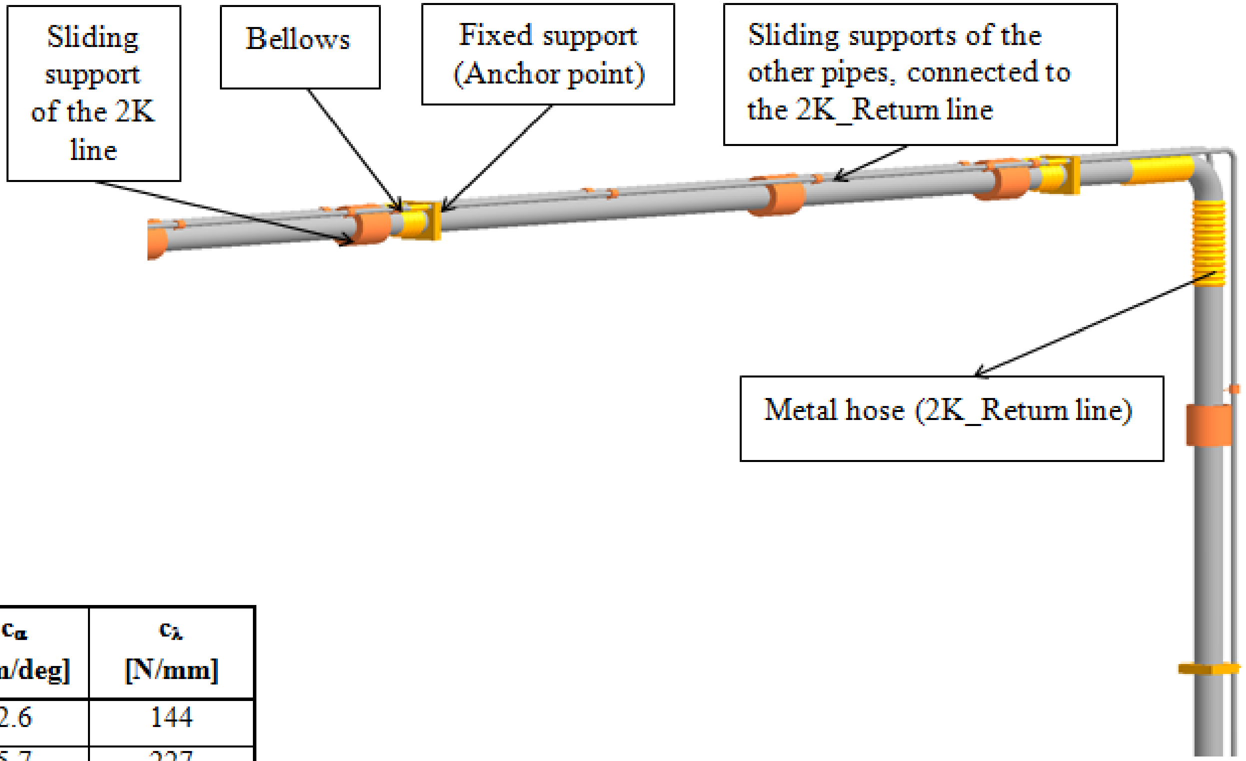
- **design condition -** calculation pressure PC corresponds with PS (set pressure); calculation temperature TC with operating temperature T_n,
- **pressure test** (*PT* = 1.43PS),
- **commissioning scenario** – the pressure value for each pipe is PC = -1 [bar g], TC=295 K
- **simulation of the process pipes misalignment** - operating conditions are the same as in design condition;
  additionally for process pipes analisys lateral displacement of the every fixed support were applied (Dy = 3mm, Dz=1 mm),



CaePipe analysis – model development and boundary conditions

What should be included in the initial calculation model:

- calculation code (EN13480),
- material properties,
- geometry (line shape, pipes size and thicknes, position of supports, bellows, etc.),
- pressures and temperatures,
- cryogen density,
- weight of the additional installation elements - isolation, thermal clamps, etc. (by introducing weight wa = 5 [kg / m] for every pipe),
- expansion bellows parameters (axial, bending and lateral spring rate ,



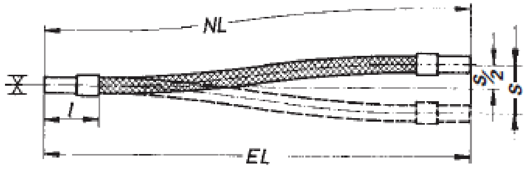
DN	PN	Type	$2\delta_N$ [mm]	$2\lambda_N$ [mm]	W [kg]	A [mm^2]	c_a [N/mm]	c_α [Nm/deg]	c_λ [N/mm]
50	25	ARN25.0050.032.1	32	15	2	4720	199	2.6	144
80	25	ARN25.0080.042.1	42	17	4	9250	222	5.7	227

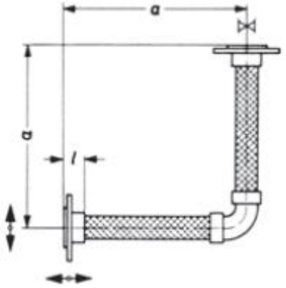
- metal hoses parameters may be estimated in following way:
  - Axial spring rate: $c_a = 1{\times}10^5$ N/mm (assumed large value corresponded to a pipe, due to a braid);
  - Bending spring rate for the metal hoses is assumed as 3 times higher than for a bellows with similar diameter;
  - Lateral spring rate $c_l = (F_{3mm}*9.81)/3$ (F_{3mm} – force in kg for 3mm metal hose displacement at appropriate internal pressure).

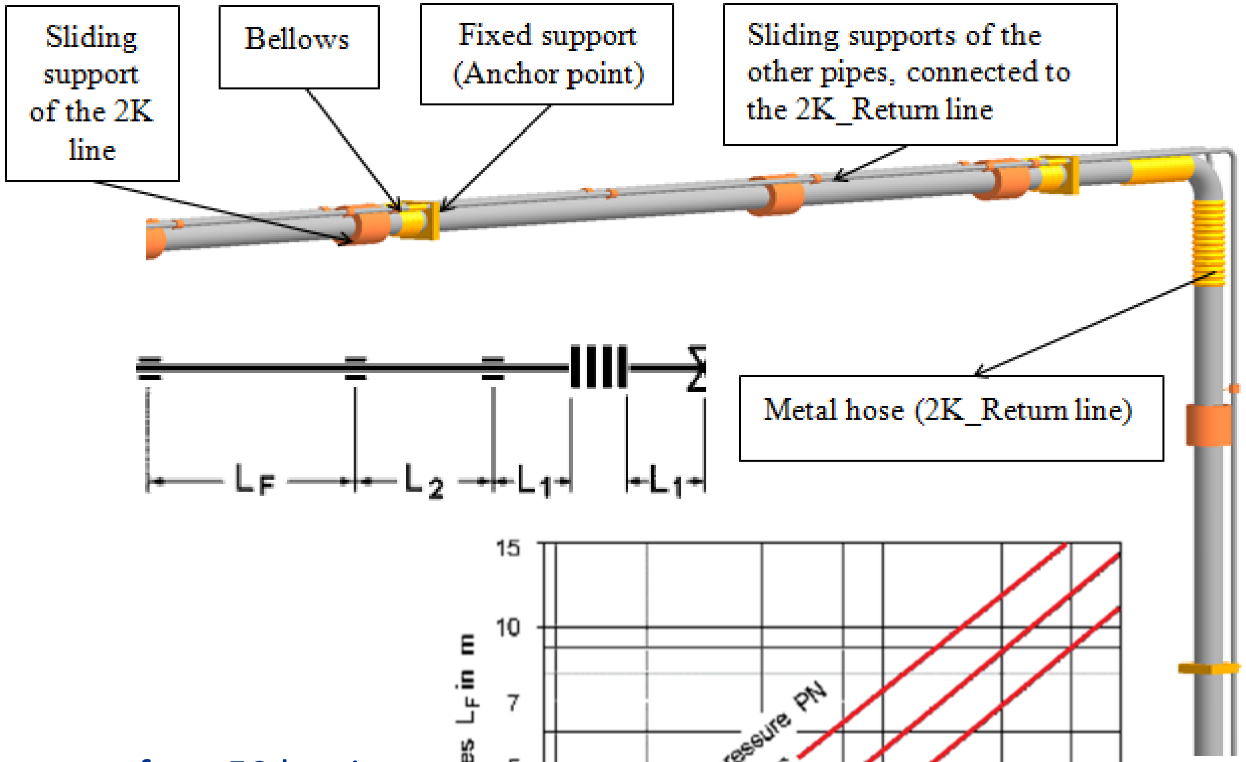
CaePipe analysis – model development and boundary conditions

What should be included in the initial calculation model:

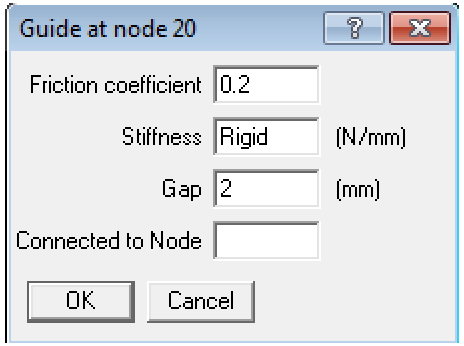
- expansion bellows supported system ($L_1 \leq 4DN$; $L_2 \leq 14DN$)
- metal hose compensation system





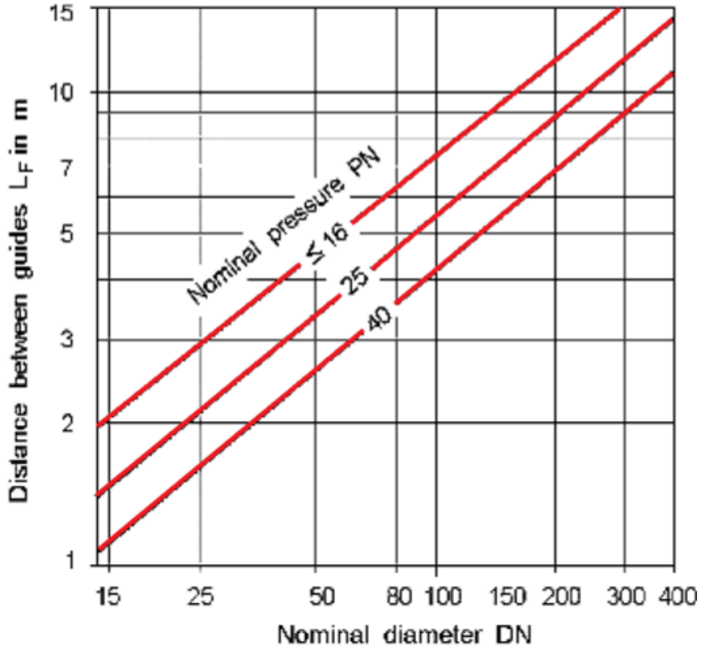


- friction and gaps in sliding supports (can be added as parameters of individual supports)



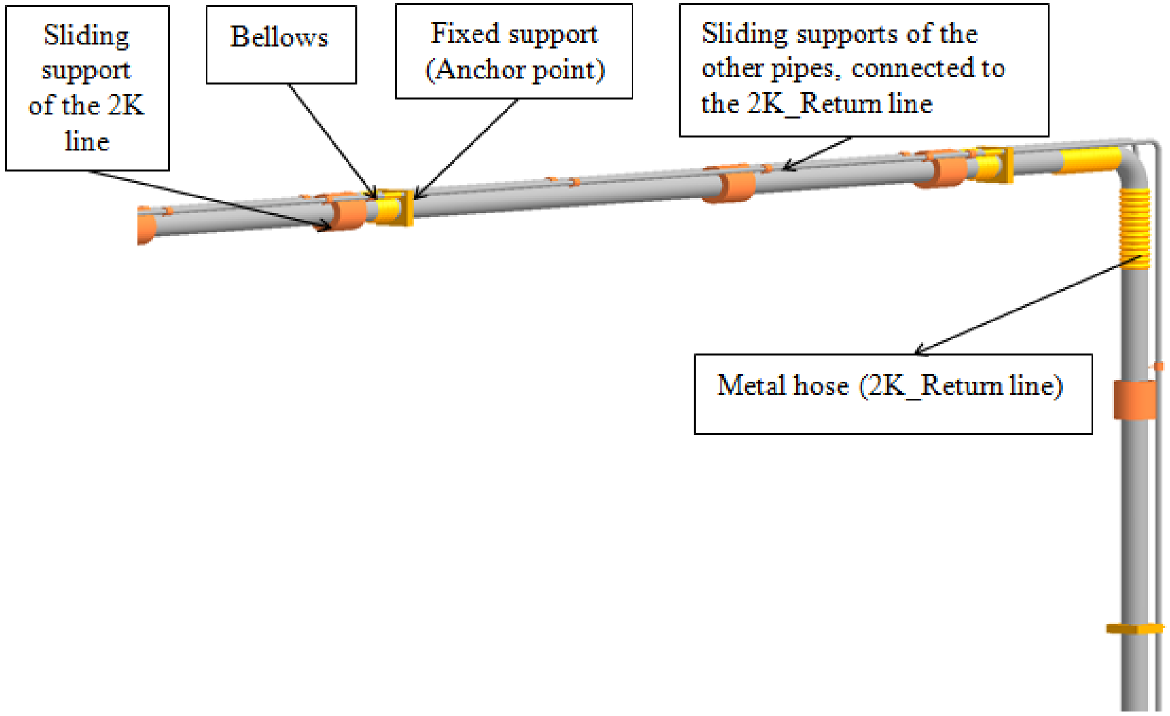
Shear force generated in a sliding support for a 50 kg pipe:

N = 500 N - force perpendicular to the support surface
μ =0.2 friction coefficient between steel and G10
F=N*μ = 500*0.2= 100N

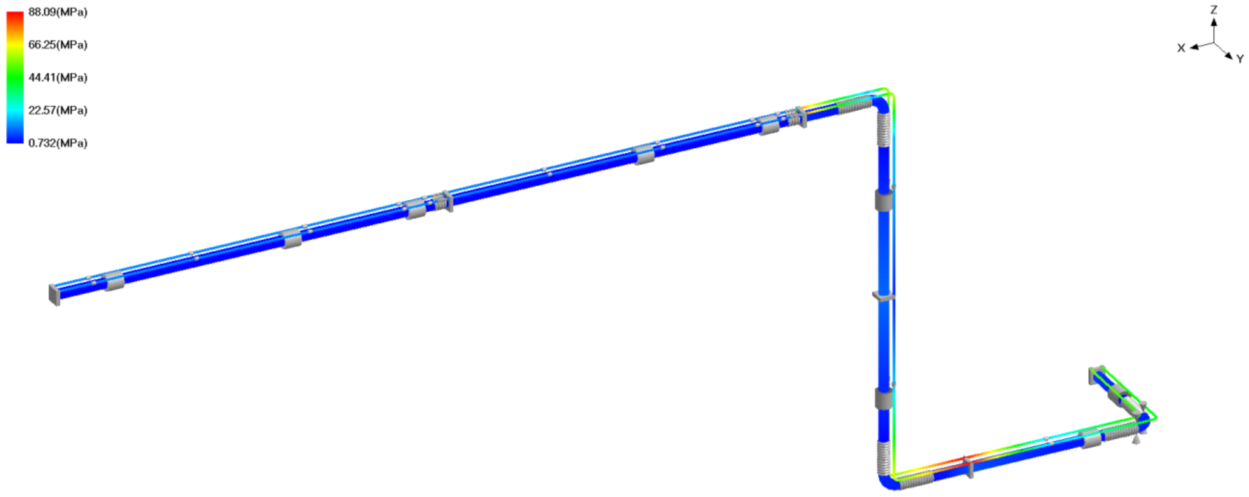


CaePipe analysis – results

- Stresses - indicate the most loaded parts of the line structure
- Deformations - indicate the displacement of individual process lines, movements of metal hoses and expansion bellows
- The values of the forces in the supports make it possible to determine the boundary conditions in order to carry out a detailed analysis of individual supports



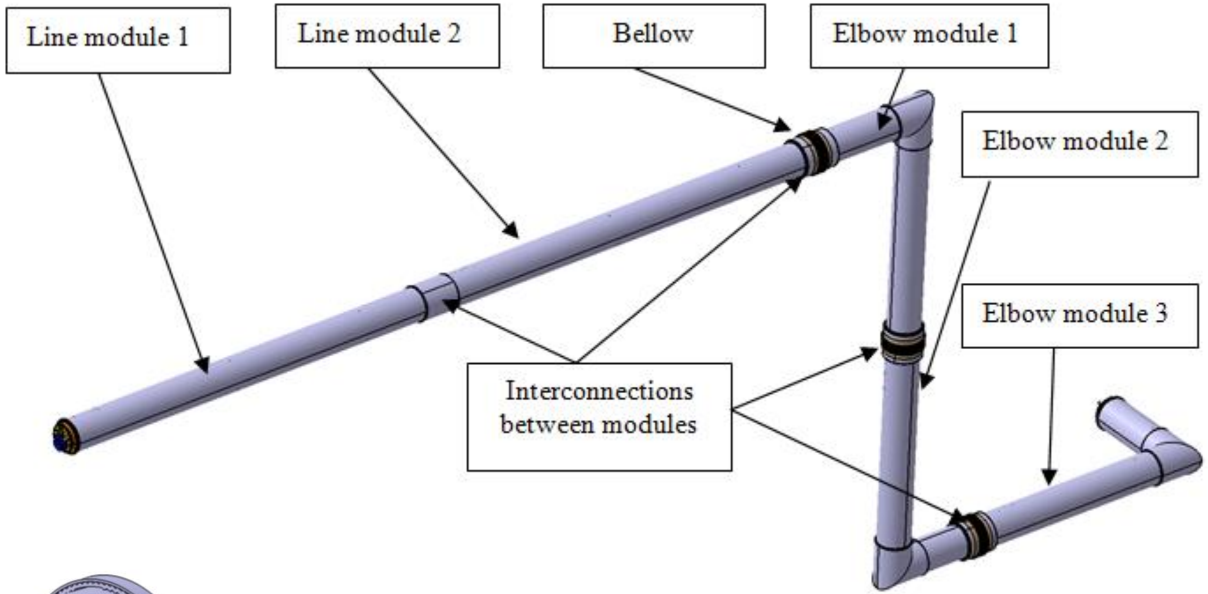
No	Parameter	2K_R	4.5K_S	CD_R	LTSS_R	HTTS_R	HTTS_S
1	DN [mm]	250	50	80	50	50	50
2	Calculation pressure PC [bar g]	4.1	20	20	20	20	20
3	Temperature [K]	3.8	4.5	10	10	80	40
4	Fluid density ρ [kg/m^3]	144	162	121	121	12	23
5	Max. sustained stress σ_1 [MPa]/(SF)	16.25 (0.11)	71.20 (0.49)	38.73 (0.27)	36.97 (0.25)	68.25 (0.47)	62.4 (0.43)
6	Max. expansion stress σ_3[MPa]/(SF)	9.46 (0.04)	87.58 (0.44)	134.6 (0.67)	88.9 (0.44)	160.6 (0.81)	93.3 (0.47)
7	Max. $\sigma_4 = (\sigma_1+\sigma_3)$ [MPa]/(SF)	23.48 (0.07)	119.1 (0.35)	146.3 (0.43)	101.6 (0.3)	175.3 (0.51)	113.21 (0.33)
8	Max. movement of a flex. element [mm]	32.5	32.5	32.5	32.5	31.8	31.8

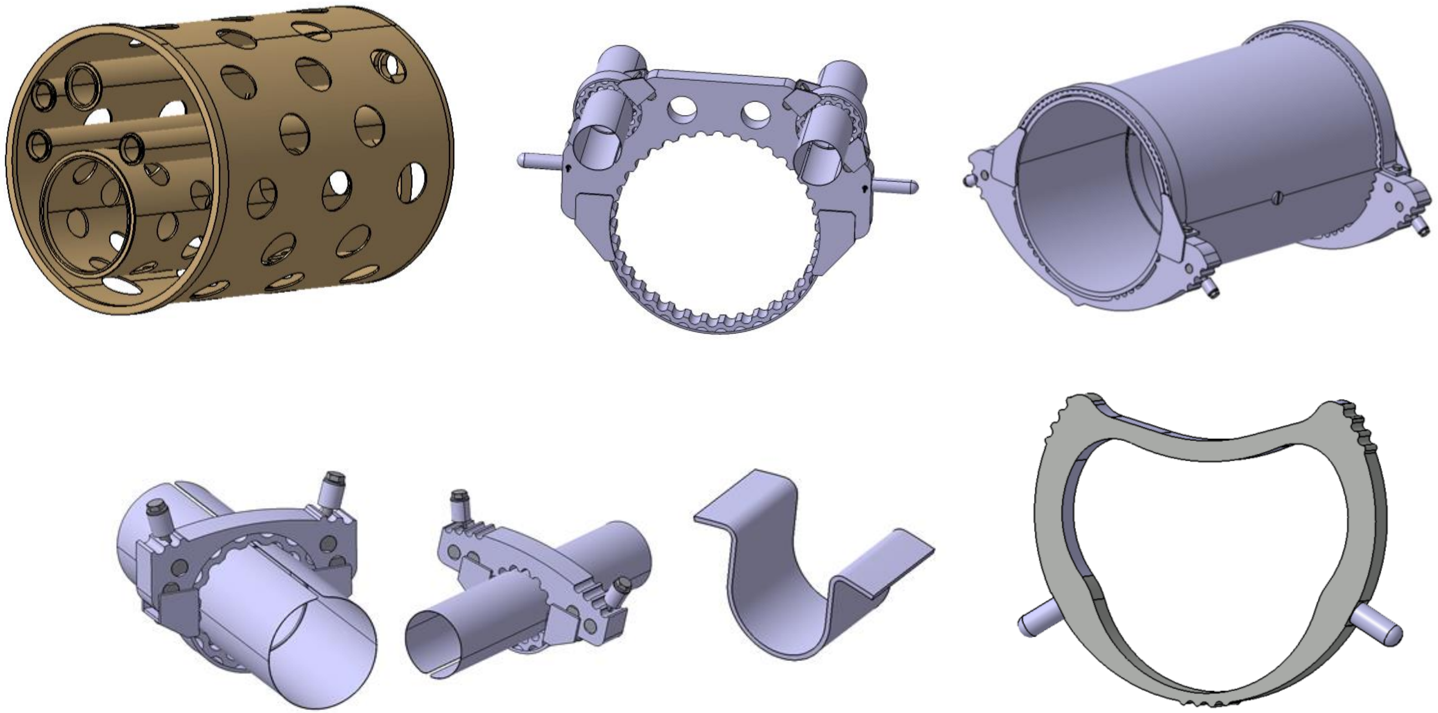


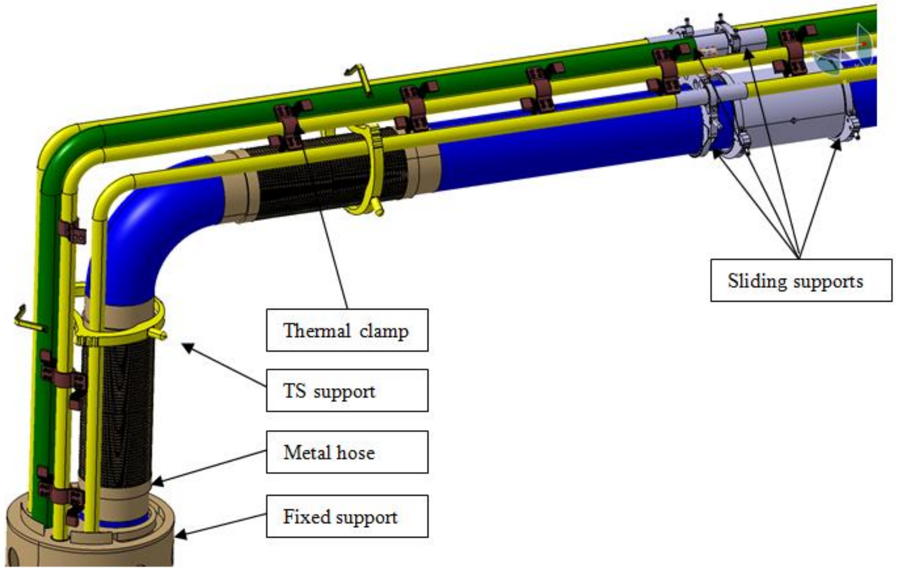
3D model development

Based on the results obtained with CaePipe, a 3D model should be made:

- design fixed and sliding supports,
- finally select the expansion bellows and metal hoses
- divide the transferline into modules



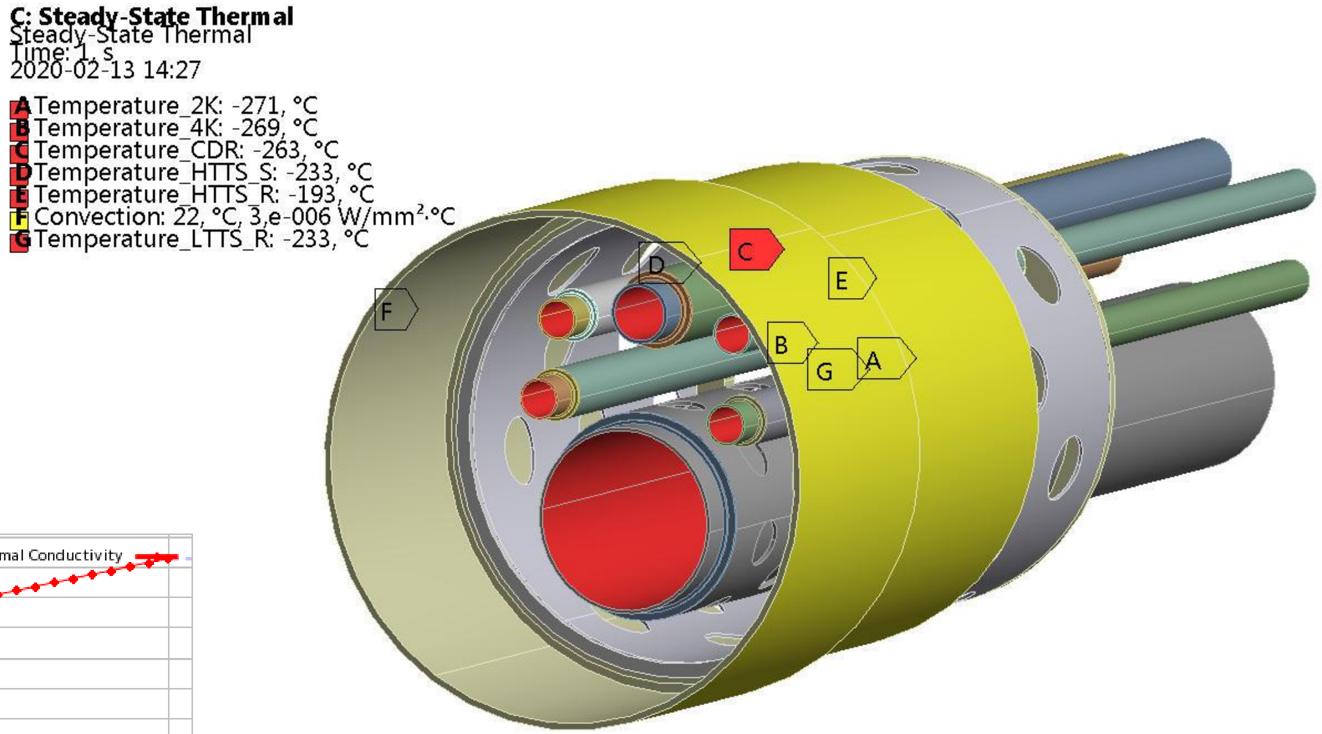


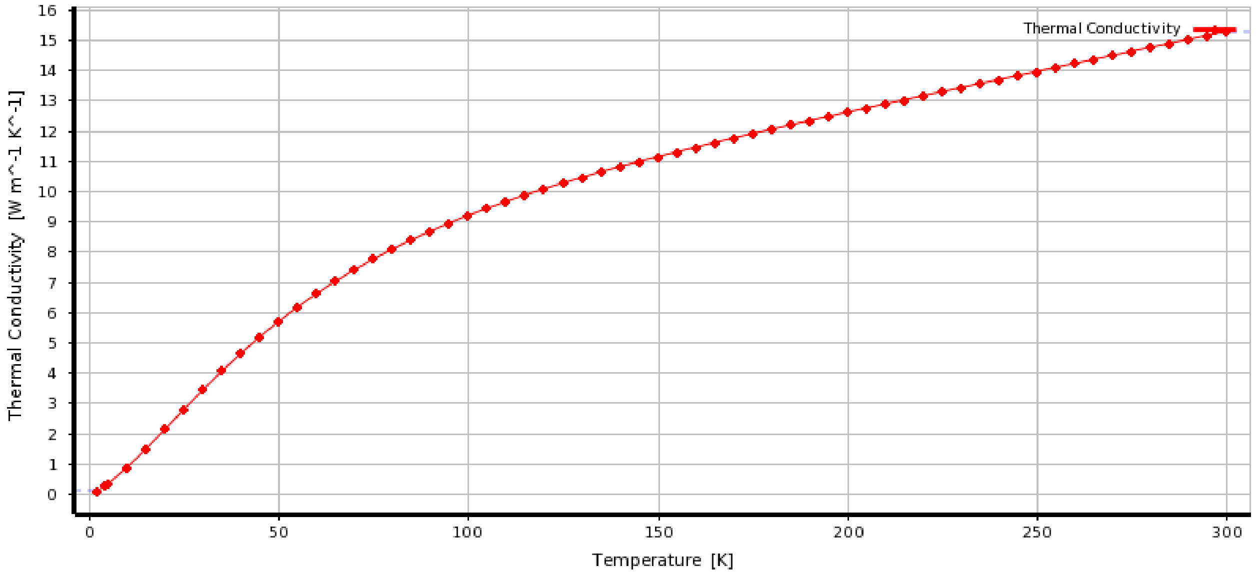


Thermal analysis of fixed support - boundary conditions

For thermal analysis, the boundary conditions specified for the fixed support should include:

- temperature of individual process pipes,
- convection coefficient on the vacuum jacket,
- thermal conductivity coefficient for the materials of the supports.





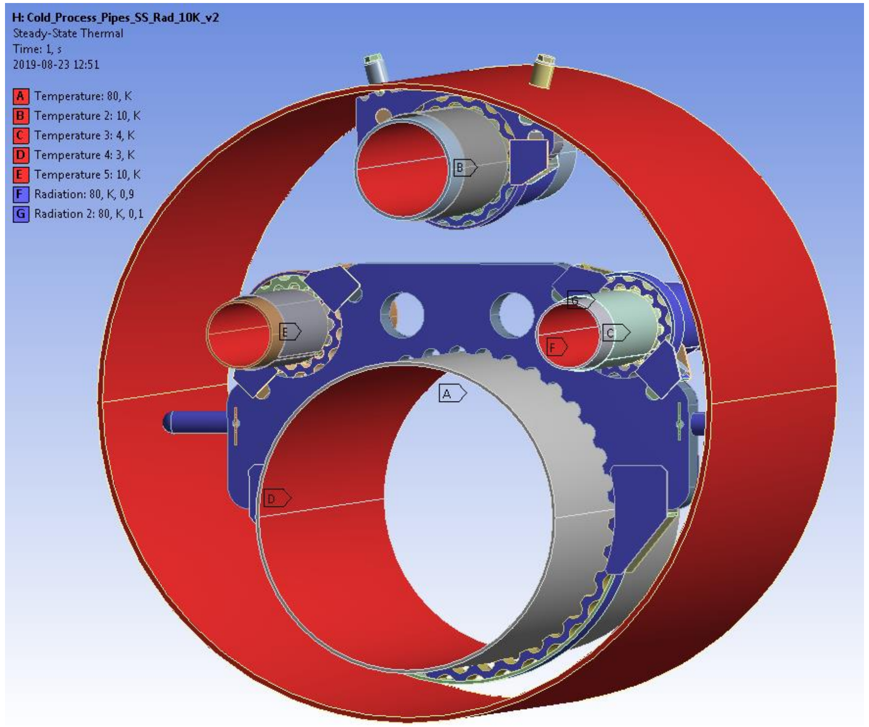
Convection coefficient can be taken as:

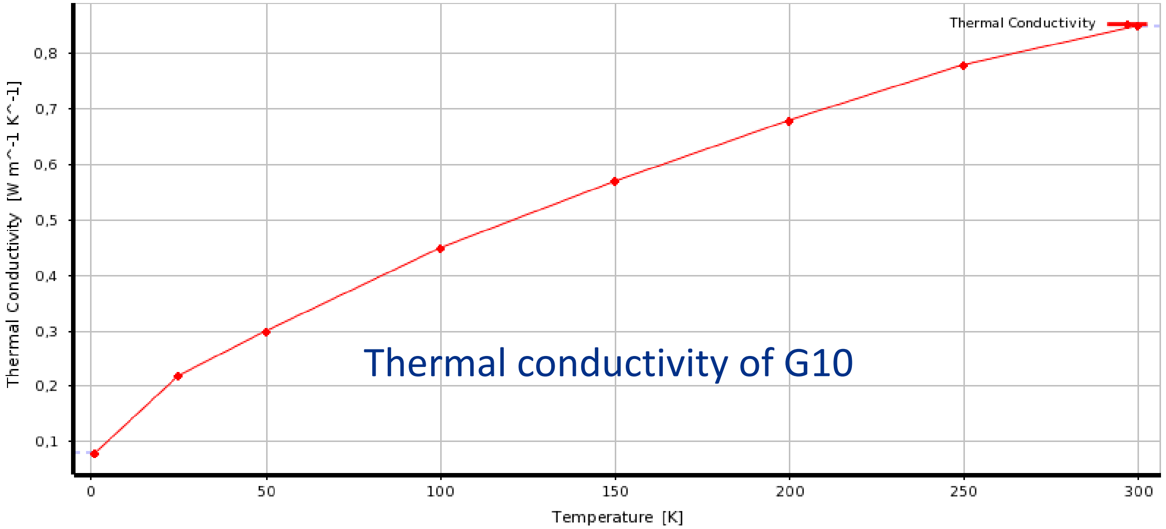
- $2 W/m^2K$ - for horizontal surfaces,
- $5 W/m^2K$ - for vertical surfaces
- (for example above $3 W/m^2K$ was assumed)

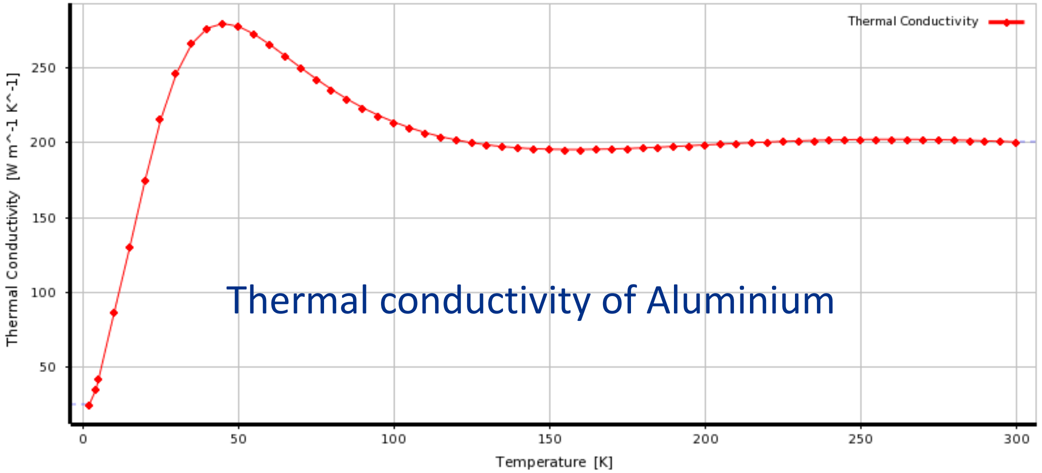
Thermal analysis of sliding supports - boundary conditions

For thermal analysis, the boundary conditions specified for the sliding support should include:

- temperature of individual process pipes,
- temperature of thermal shield
- heat flows by radiation to surfaces not covered with MLI,
- thermal conductivity coefficient for the materials of the supports.
- in a conservative approach, the contact resistance coefficient can be omitted (the obtained heat flux will be higher than the real ones)





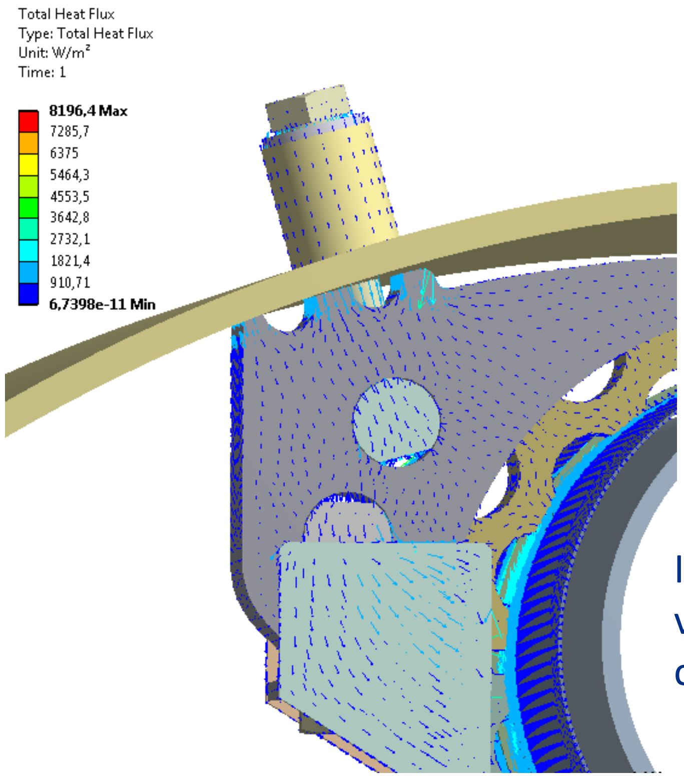


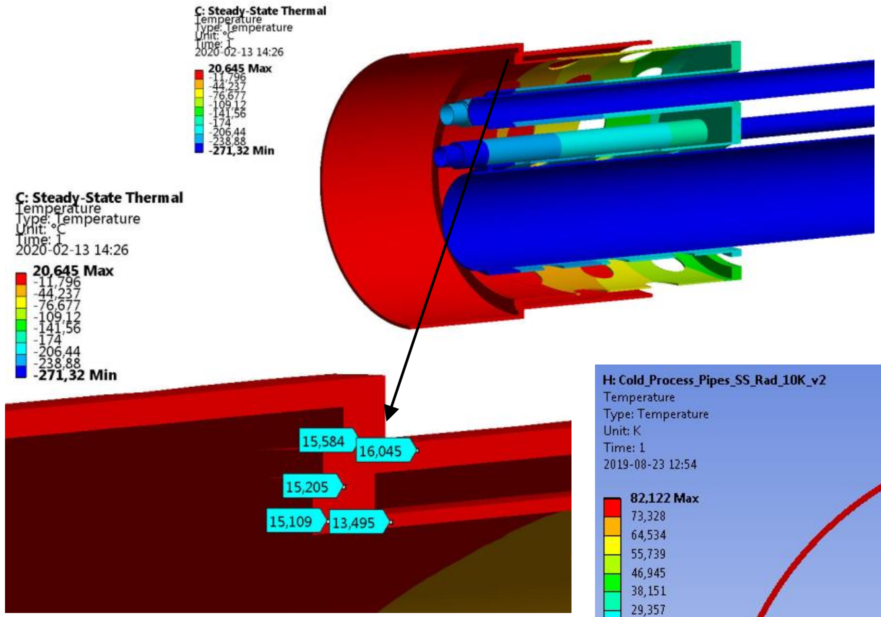
Thermal analysis of sliding supports - results

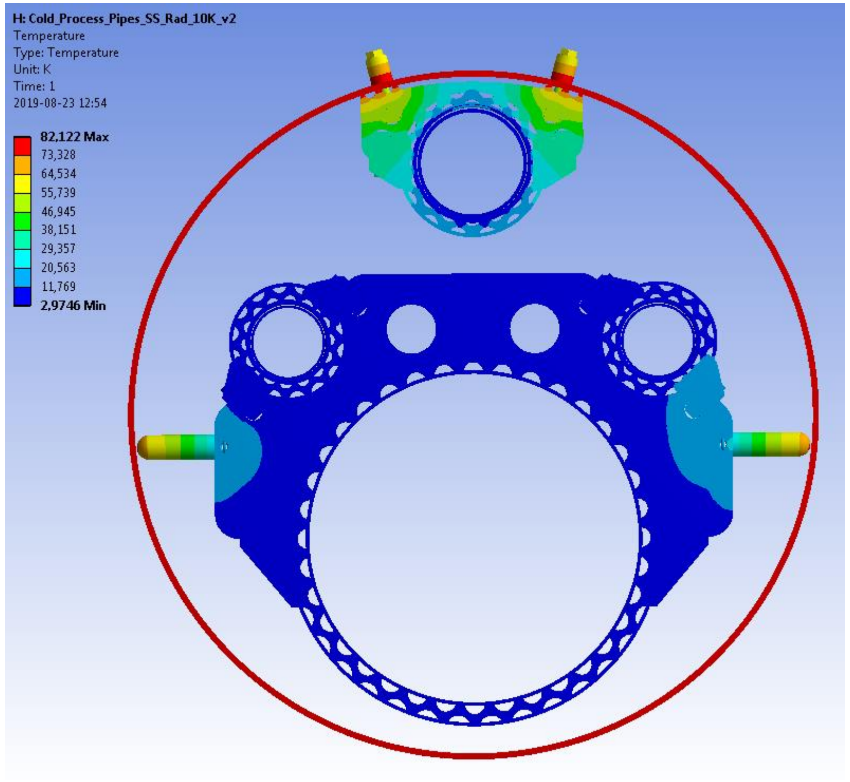
The result of the thermal analysis of the fixed support:

- heat flux to the process pipes
- temperature value at the coldest point of the vacuum vessel should not be below the dew point

The result of the thermal analysis of the sliding support shows mainly the heat flux to the process pipes







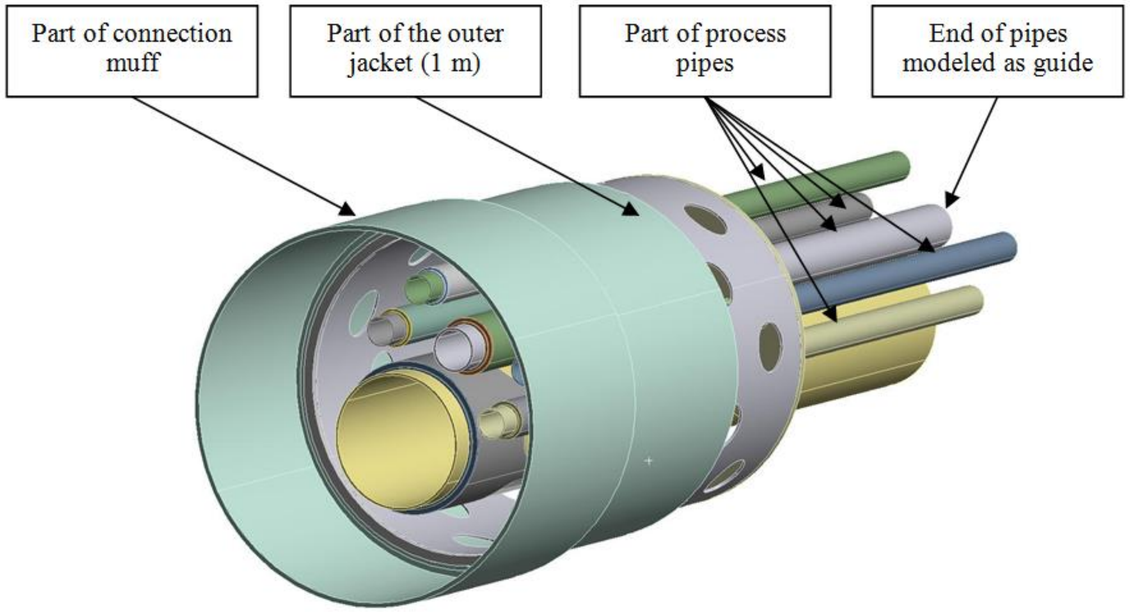
In order to verify the analyzes, the vector of the heat flux density should be checked

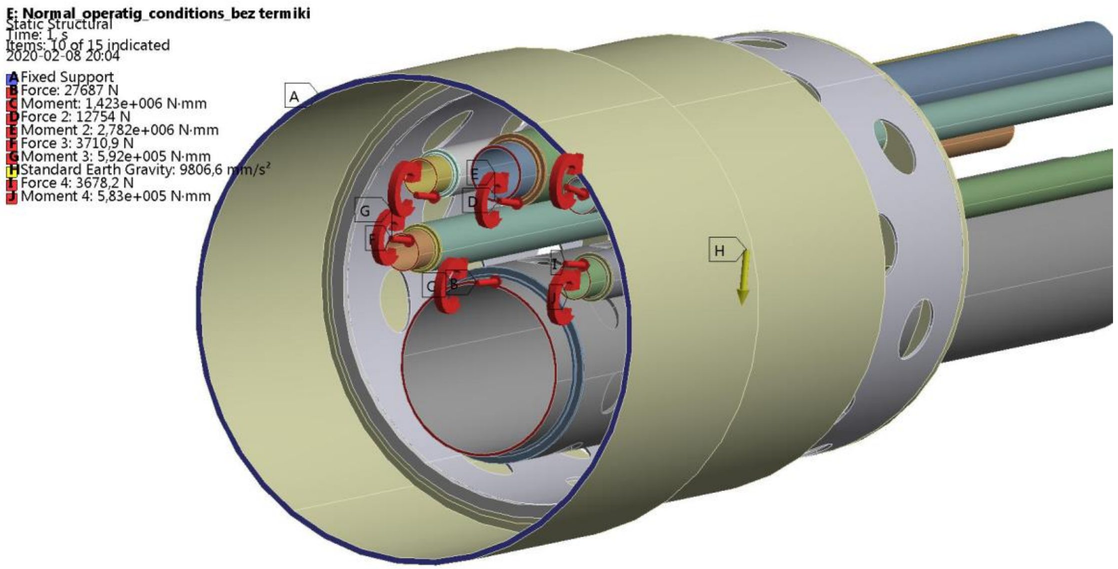
Mechanical analysis of fixed support - boundary conditions

For mechanical analysis, the boundary conditions specified for the fixed support should considered the most critical results of the CaePipe analysis.

Forces and moments components acting on the most loaded fixed support

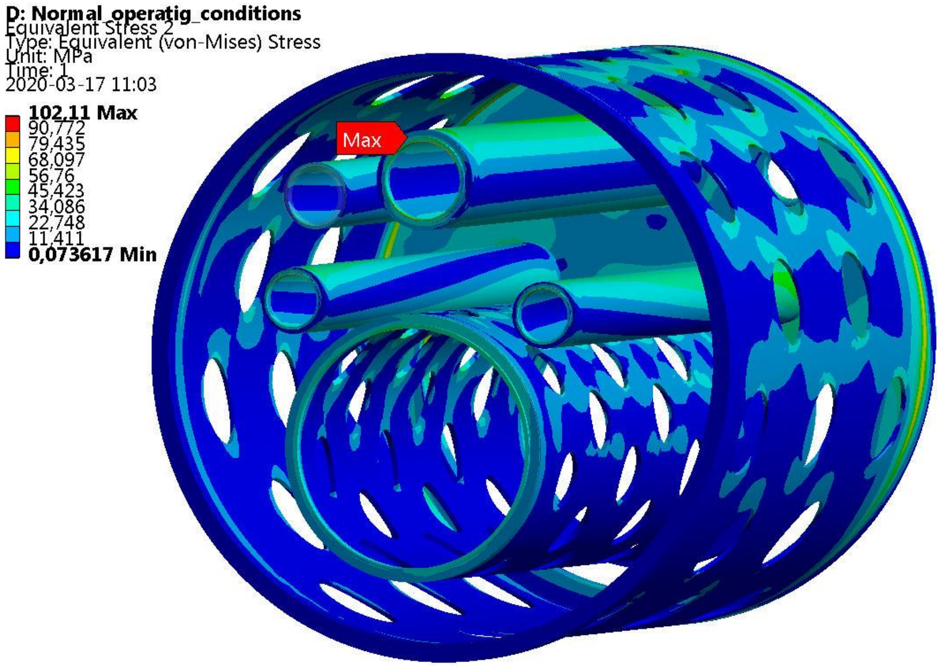
Line	FX [N]	FY [N]	FZ [N]	MX [Nm]	MY [Nm]	MZ [Nm]
FEM_LC2, FEM_LC3- normal operating conditions						
2 K_R	-27643	0	-1555	0	-1423	0
4.5 K_R	-3674	0	-552	0	-592	0
CD_R	-12603	0	-1958	0	-2782	0
LTTS_R	-3648	0	-470	0	-582	0
HTTS_S	-3638	0	-519	0	-578	0
HTTS_R	-4179	0	-1230	0	-1128	0

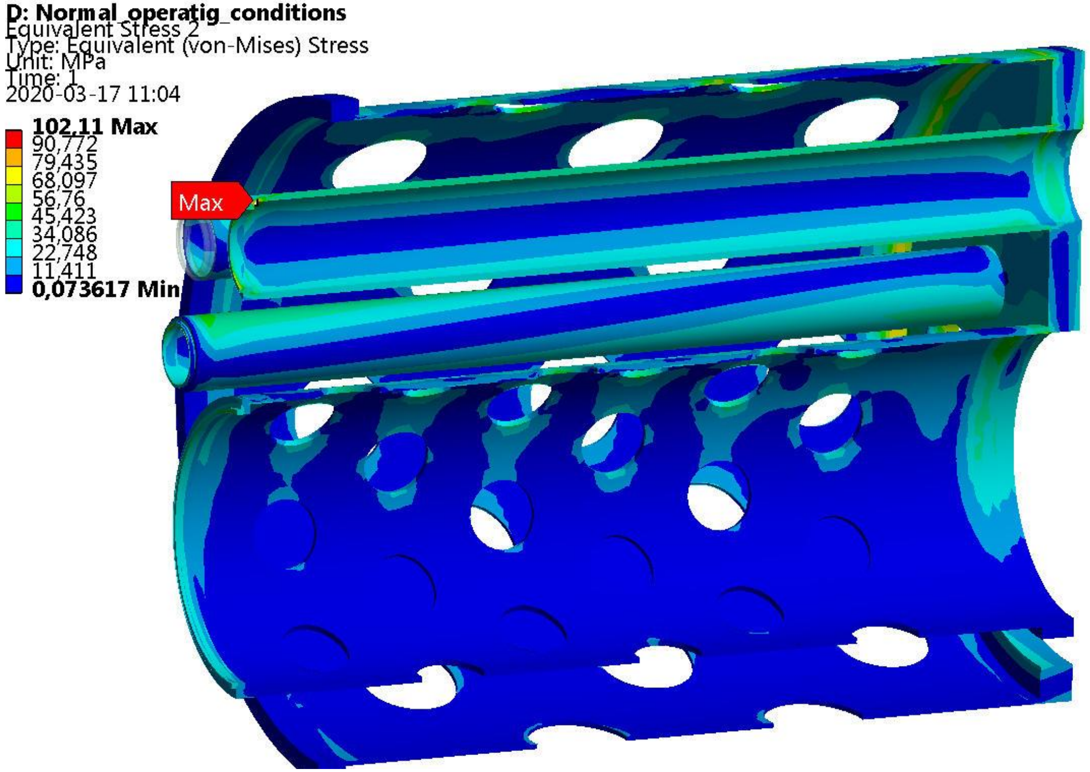


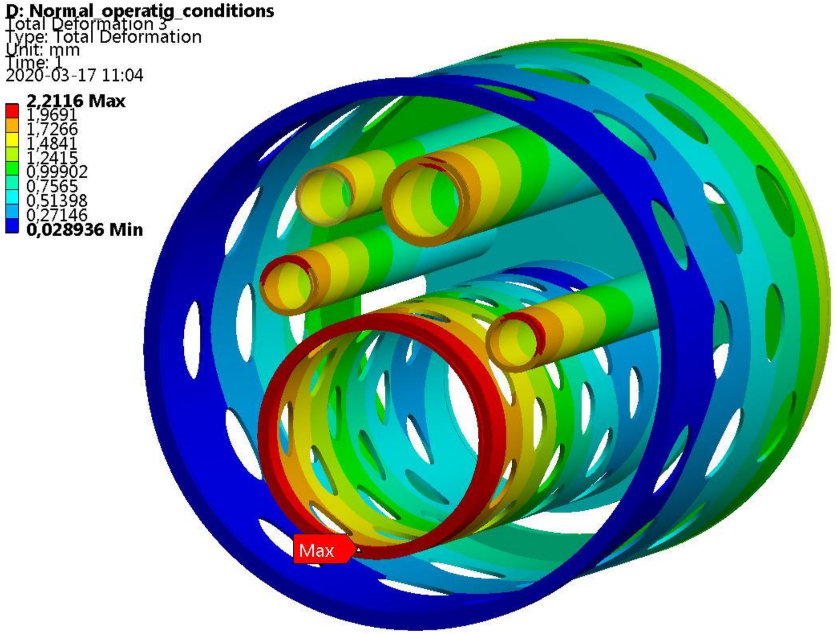


Mechanical analysis of fixed support - results

- the value of max. stress (102.11 MPa) should be lower than the allowable (f_h+f_a=341.8 MPa),
- the deformation should be below the permissible value for the given load case
- in the case of compression elements, backing analysis should be considered



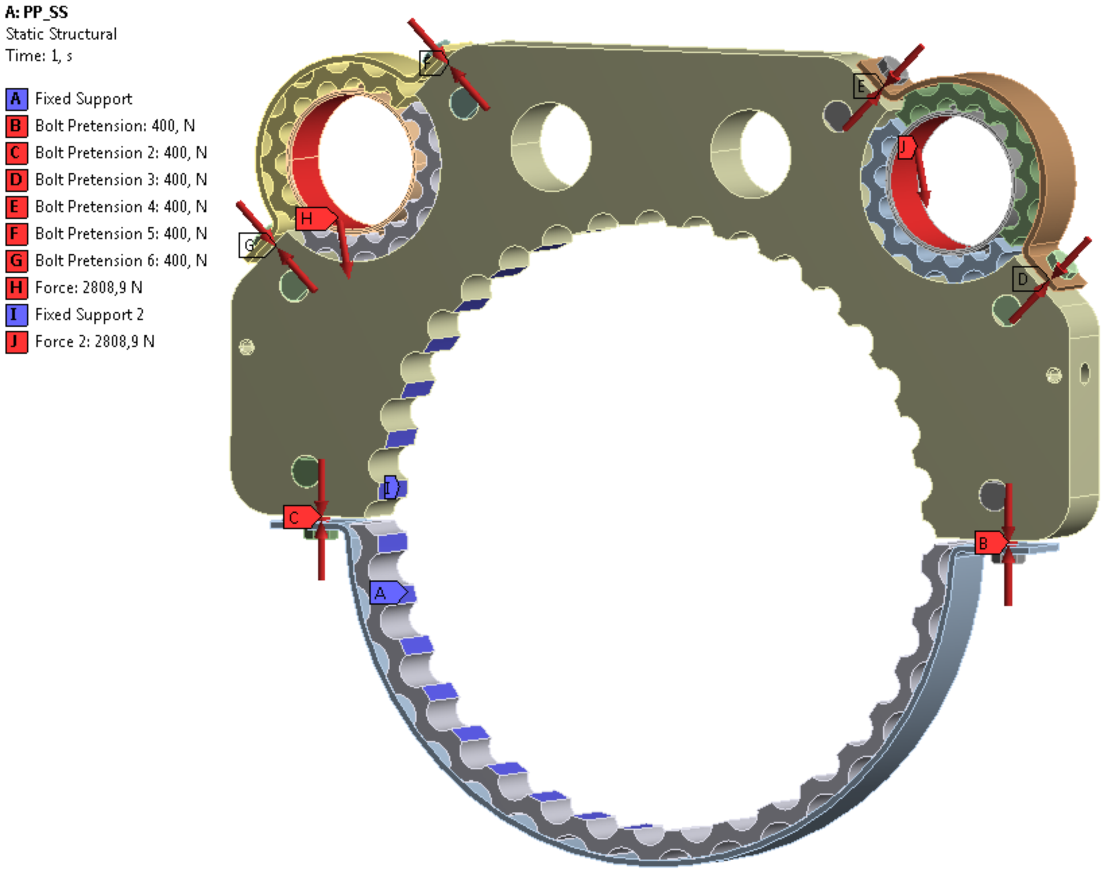


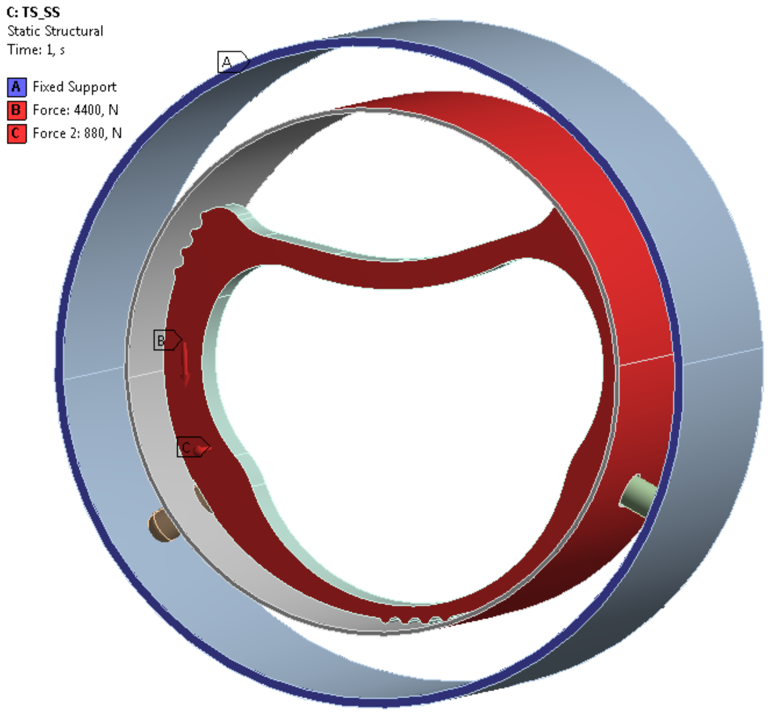


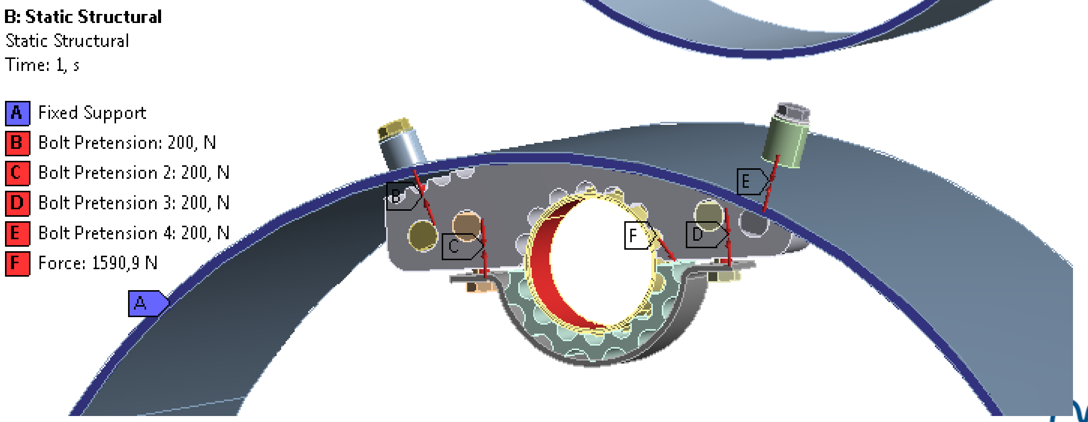
Mechanical analysis of fixed sliding support - boundary conditions

In the case of a thermal shield support, the friction force should be taken into account F=N*μ = 4400*0.2= 800N

For mechanical analysis, the boundary conditions specified for the supports should considered the most critical results of the CaePipe analysis.

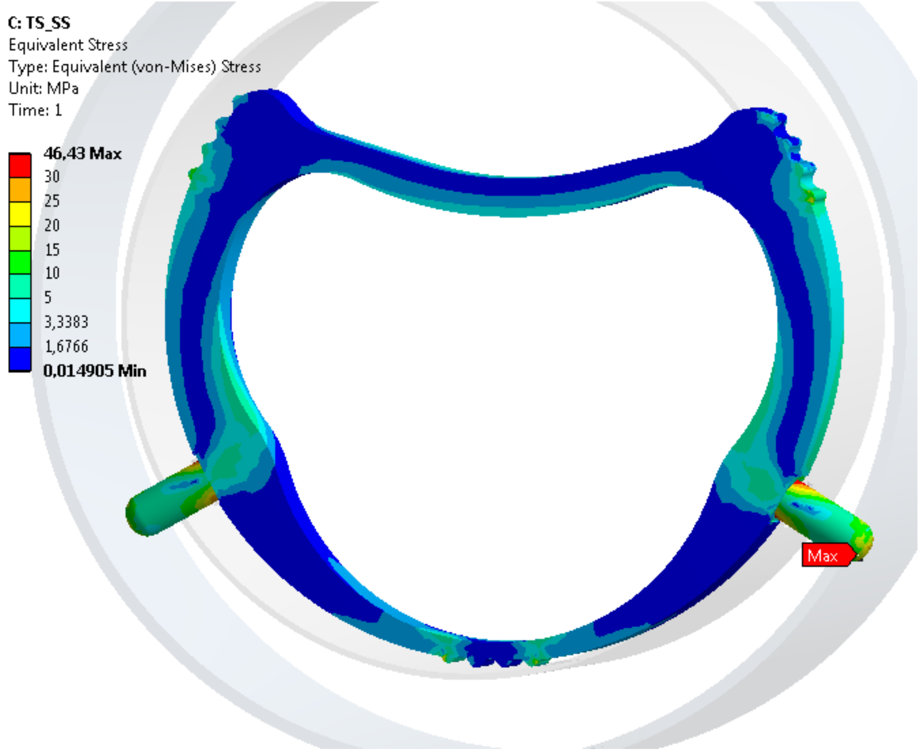


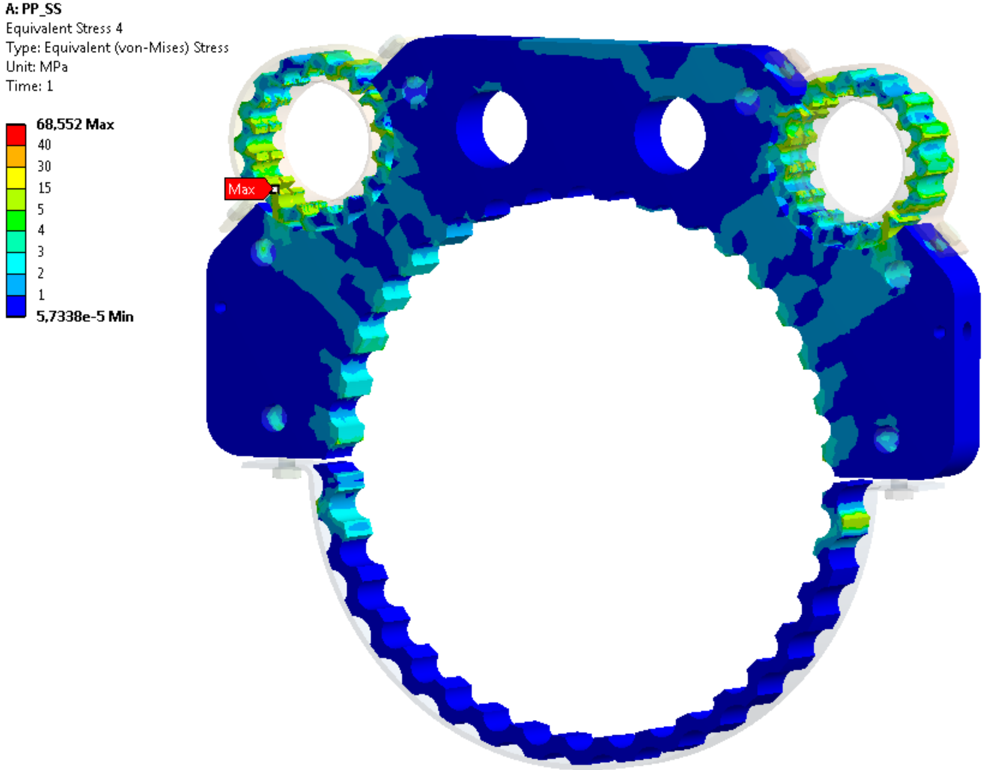


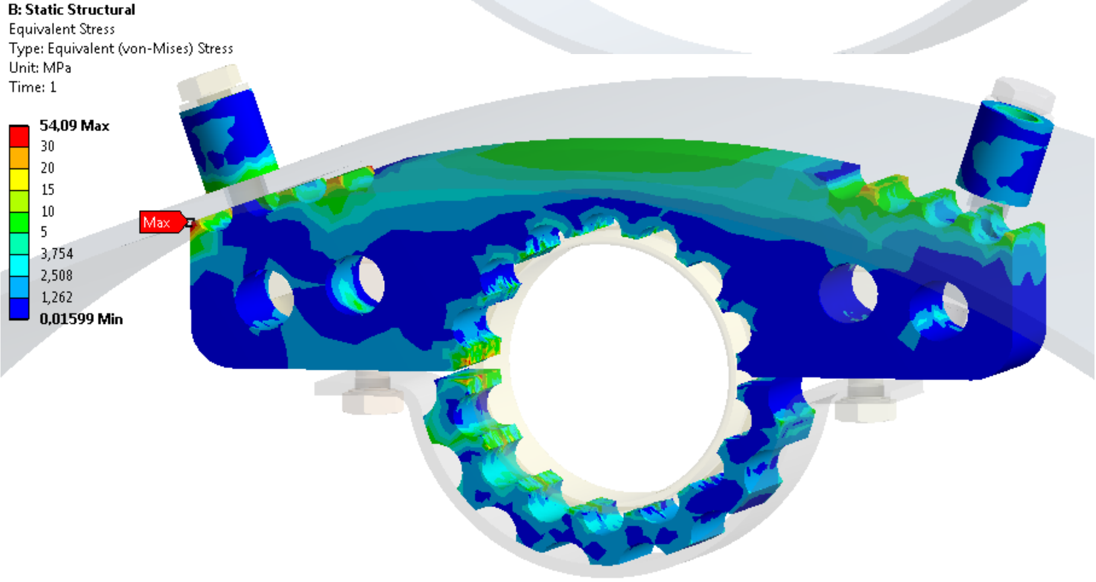


Mechanical analysis of sliding support - results

- the value of max. stress (68.6 MPa) should be lower than the allowable (for G10 f=R_m/3 = 86.6MPa) [www.matweb.com],
- elements made of different materials should be analyzed on a separate stress scale due to different values of allowable stresses



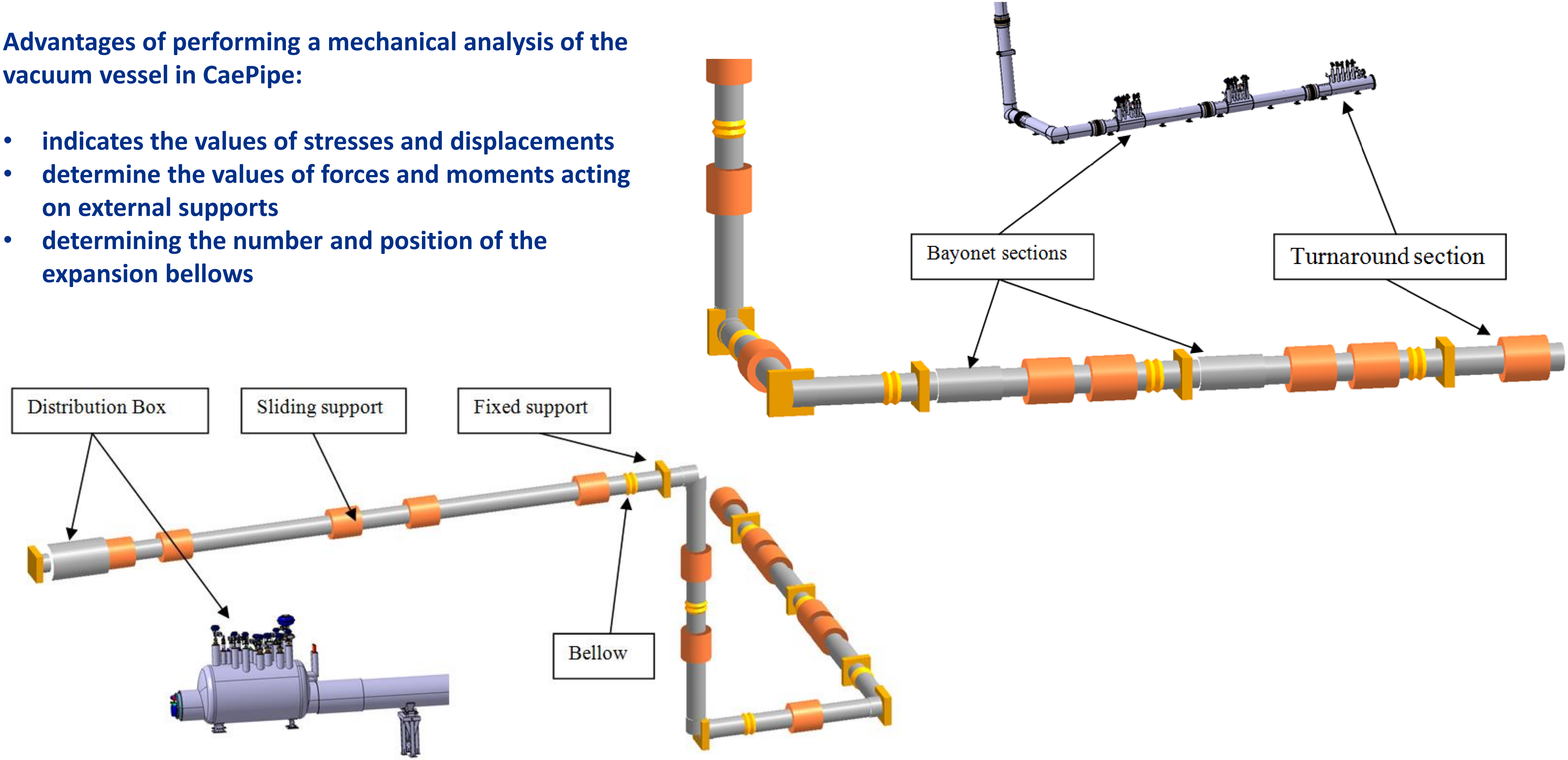




Mechanical analysis of vacuum vessel – CaePipe model

Advantages of performing a mechanical analysis of the vacuum vessel in CaePipe:

- **indicates the values of stresses and displacements**
- **determine the values of forces and moments acting on external supports**
- **determining the number and position of the expansion bellows**



Mechanical analysis of external supports - boundary conditions

For mechanical analysis, the boundary conditions specified for the external fixed and sliding supports should considered the most critical results of the CaePipe analysis.

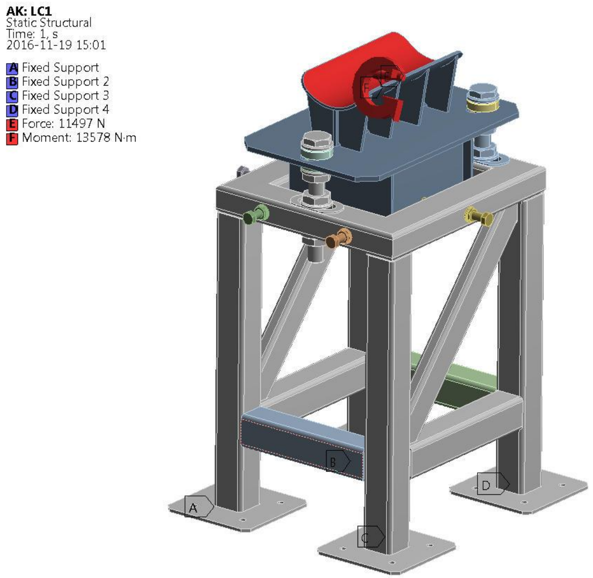


Table 9.5 Force and moment components acting on the fixed support

Node	F_X [N]	F_Y [N]	F_Z [N]	M_X [Nm]	M_Y [Nm]	M_Z [Nm]
LC1 - normal operating conditions						
4000	2544	10957	-2812	-16736	134	4718
LC2, LC3 - failure operating conditions						
4000	-15314	-6044	-2234	8002	704	-2048

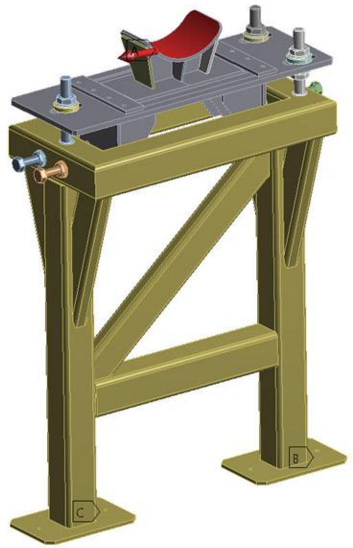
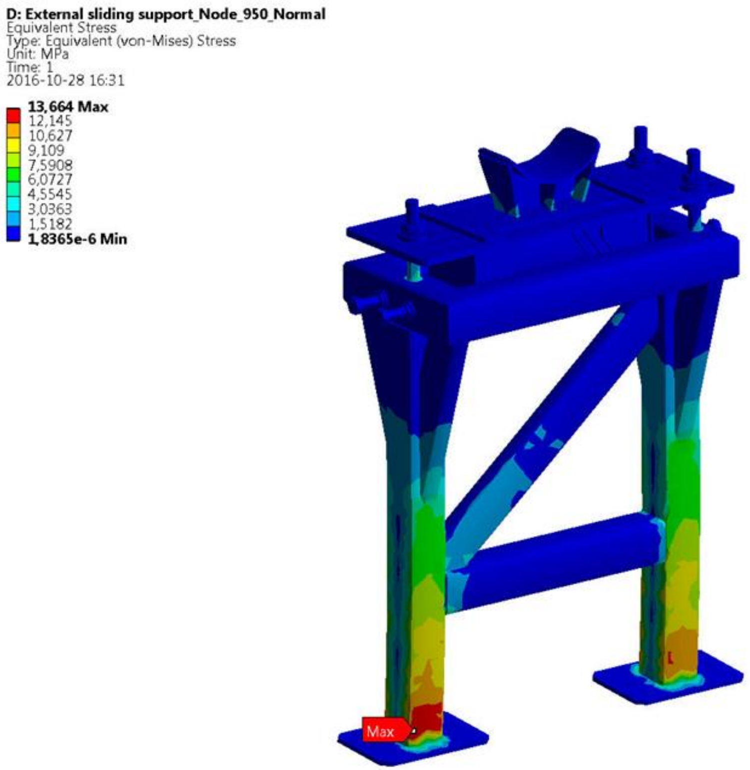


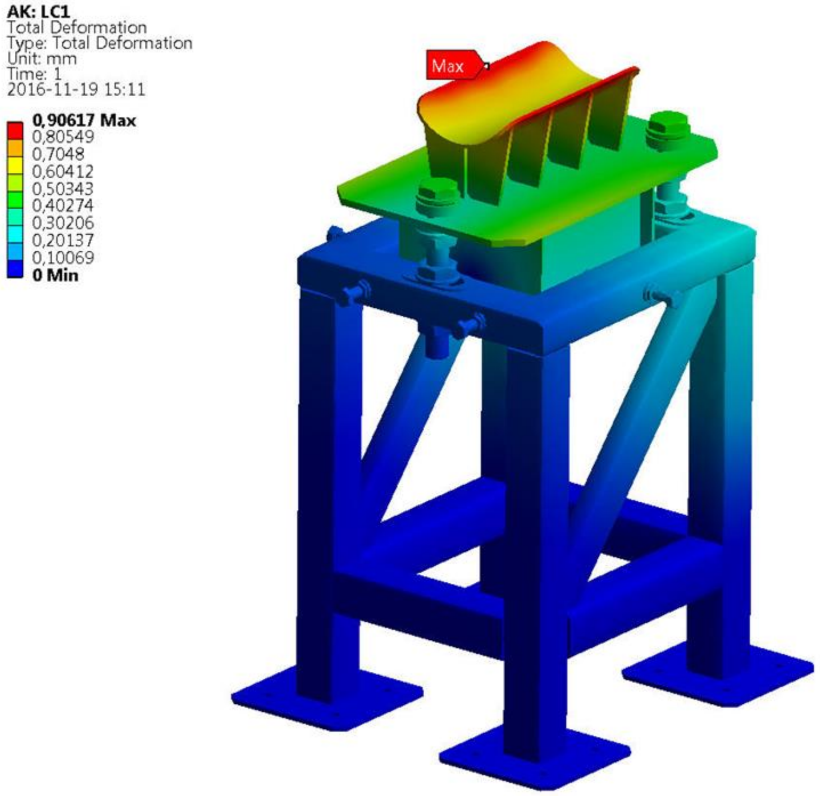
Table 9.6 Force components acting on the sliding support

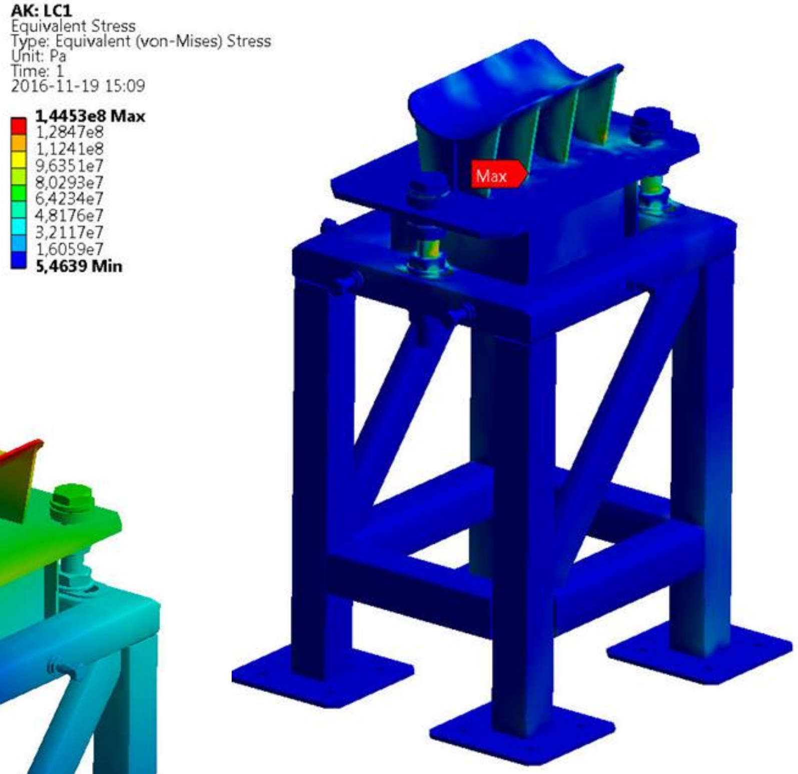
Node	F_X [N]	F_Y [N]	F_Z [N]
LC1 – normal operating conditions			
1100	-385	-1592	-1079
LC2 – failure operating conditions			
1100	5444	-26871	4356

Mechanical analysis of external supports - results

- **the value of max. stress (144.5 MPa) should be lower than the allowable (fh = 153.3 MPa),**
- **the deformation should be below the permissible value for the given load case**
- **in the case of compression elements, backing analysis should be considered**







Summary

Caepipe software works well for pre-analysis of long-length models with a large number of repetitive elements.

Changes of initial calculation model is not very time consuming.

Simple analysis and modification of the compensation system.

Obtaining preliminary results allows for faster and more efficient design of the 3D model.

The obtained results of loads can be used in a detailed mechanical analysis of 3D models.

Thank you for your attention